Turboprop engine

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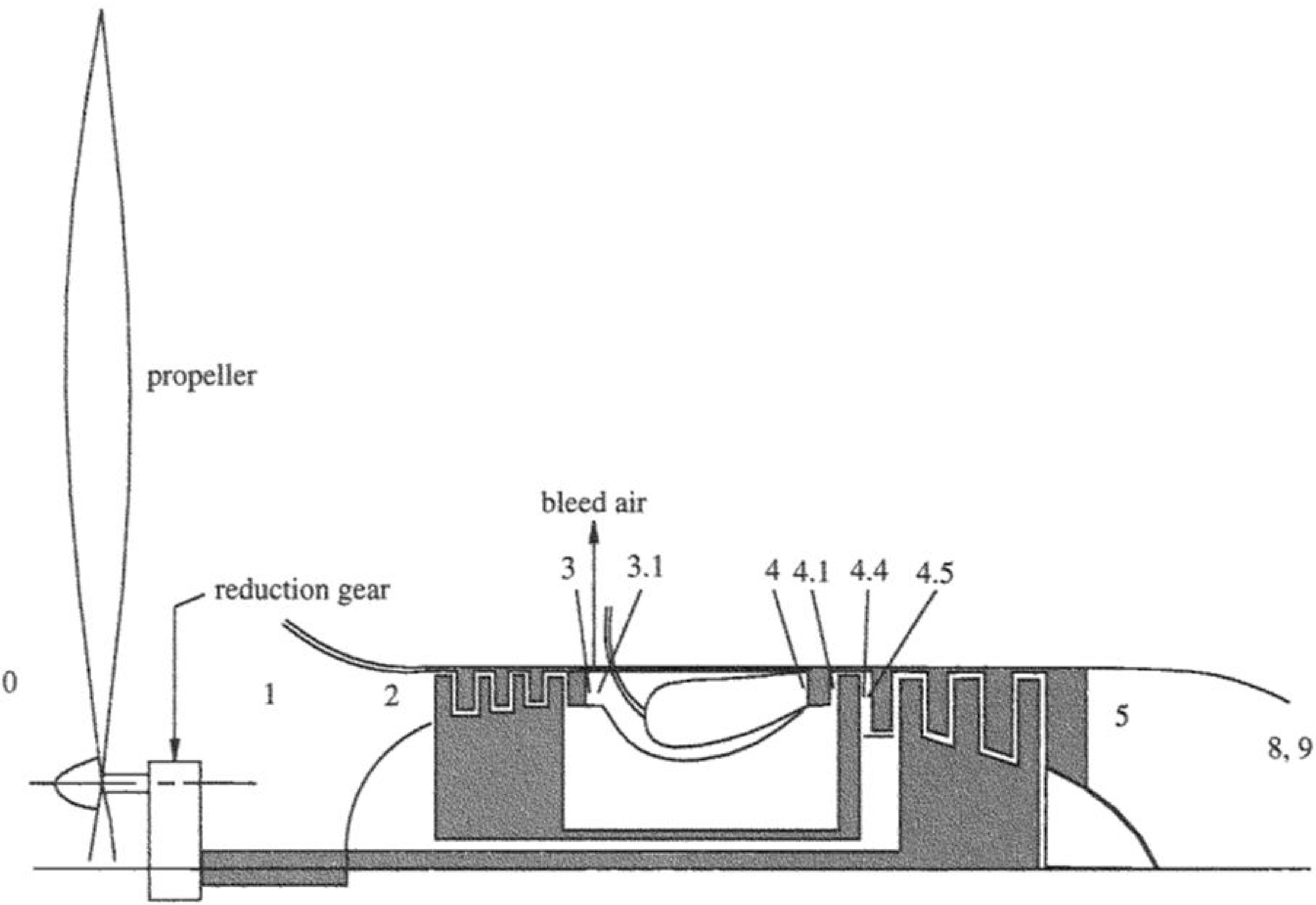
TURBOPRO ENGINE

En example of turboprop engin calculation is presented below.



Given

T0=288 K, P0=100 kPa, M0=0.2, compressor pressure ratio 8, Turbine inlet temperature Tt4=1300 K, outlet diffuser flow spees M9=0.3.

inlet pressure losses coefficient σ_{IN} 0.96, burner pressure losses coefficient σ_B 0.98, exit diffuezer pressure losses coefficient σ_N 0.95, compressor efficeincy η_C 0.80, compressor turbine efficiency η_T 0.82, power turbine efficiency η_{PT} 0.85, burner efficiency η_B 0.98, mechanical efficiency η_M = 0.99, power turbine mechanical efficiency and gear efficiency η_G = 0.95

Calculate:

1) Pressure and temperature distribution in the turboprop engine

2) Air mass flow and specific fuel consumption for 1000 kW shaft power.

Gas parameters:

Air: k=1.4; cp=1005 J/kg/K, R=287 J/kg/K,

Fumes in turbine and nozzle kt=1.33, cpt=1170 J/kg/K, Rt=290 J/kg/K,

For combustion in combustor cpB=1200 J/kg/K,

Fuel heat value: FHV=43 MJ/kg

Flight Mach No

```
M0 = 0.2000
```

Air Mass flow [kg/s]

```
m0 = 1
```

Turbine inlet temperature [K]

```
Tt4 = 1300
```

Compressor pressure ratio

```
CPR = 8
```

Ambient conditions

Static temperature [K]

```
T0 = 288
```

Static pressure [Pa]

```
P0 = 100000
e_G = 0.9500
```

Assumed engine exit flow velocity Mach No

Assumed power of Shaft Power Turbine [W]

Turboprop engine temperature and pressure distribution calculation.

Section 0

Total temperature [K]

$T_{t0} = T_0\left(1 + \frac{k-1}{2} M_0^2\right)$ - like for ideal engine

```
Tt0 = 290.3040
```

Total pressure [Pa]

$$P_{t0} = P_0\left(1 + \frac{k-1}{2} M_0^2\right)^{\frac{k}{k-1}}$$

```
Pt0 = 1.0283e+05
```

Speed of sound [m/s]

$$a_0 = \sqrt{k * R * T_0}$$

```
a0 = 340.1741
```

Flight speed [m/s]

$V_0 = M_0 * a_0$ - like for ideal engine

```
V0 = 68.0348
```

Section 2 Compressor inlet

Total temperature [K]

$T_{t2} = T_{t0}$ - like for ideal engine

```
Tt2 = 290.3040
```

Total pressure [Pa]

$$P_{t2} = \sigma_{\mathrm{IN}} * P_{t0}$$

```
Pt2 = 9.8715e+04
```

Section 3 - Compressor outlet / Burner inlet

Total temperature [K]

$$T_{t3} = T_{t2} * \left(1 + \frac{\mathrm{CPR}^{\frac{k-1}{k}} - 1}{\eta_C}\right)$$

```
Tt3 = 584.7620
```

Total pressure [Pa]

$$P_{t3} = P_{t2} * \mathrm{CPR}$$

```
Pt3 = 7.8972e+05
```

COMPRESSOR

Compressor work [J/kg]

$W_C = c_p * (T_{t3} - T_{t2})$

```
WC = 2.9593e+05
```

Compressor power   [W]

$P_C = m_0 * W_C$

```
PC = 2.9593e+05
```

Section 4 Burner outlet / Turbine inlet

Total temperature   [K]

T_{t4}

```
Tt4 = 1300
```

Total pressure   [Pa]

$P_{t4} = \sigma_B * P_{t3}$

```
Pt4 = 7.7393e+05
```

BURNER

Fuel-air ratio

$$f_B = c_{pB} * \frac{T_{t4} - T_{t3}}{\mathrm{FHV} * \eta_B}$$

```
fB = 0.0204
```

Section 45   Compressor turbine outlet

Total temperature   [K]

$$T_{t45} = T_{t4} - \frac{W_C}{\eta_M * (1 + f_B) * c_{pt}}$$

```
Tt45 = 1.0496e+03
```

Total pressure [Pa]

$$P_{t45} = P_{t4}\left(\frac{\eta_T + \frac{T_{t45}}{T_{t4}} - 1}{\eta_T}\right)^{\frac{\mathrm{kt}}{\mathrm{kt}-1}}$$

```
Pt45 = 2.6308e+05
```

Engine exit diffuser and power turbine calculation

Static pressure in engine outlet:

$P_9 = P_0$

```
P9 = 100000
```

Total pressure in engine outlet:

$$P_{t9} = P_9\left(1 + \frac{k_t - 1}{2} M_9^2\right)^{\frac{k_t}{k_t - 1}}$$

```
Pt9 = 1.0612e+05
```

Section 5

Total pressure

$$P_{t5} = \frac{P_{t9}}{\sigma_N}$$

```
Pt5 = 1.1171e+05
```

Total temperature   [K]

$$T_{t5} = T_{t45}\left[1 - \eta_{PT}\left(1 - \left(\frac{P_{t5}}{P_{t45}}\right)^{\frac{kt-1}{kt}}\right)\right]$$

```
Tt5 = 878.7918
```

Section 9

$$T_{t9} = T_{t5}$$

```
Tt9 = 878.7918
```

Static temperature   [K]

$$T_9 = T_{t9} * \left(\frac{P_9}{P_{t9}}\right)^{\frac{kt-1}{kt}}$$

```
T9 = 865.9327
```

Speed of sound   [m/s]

$$a_9 = \sqrt{kt * Rt * T_9}$$

```
a9 = 577.9189
```

Jet speed   [m/s]

$$V_9 = M_9 * a_9$$

```
V9 = 173.3757
```

Temperature pressure engien distribution summary

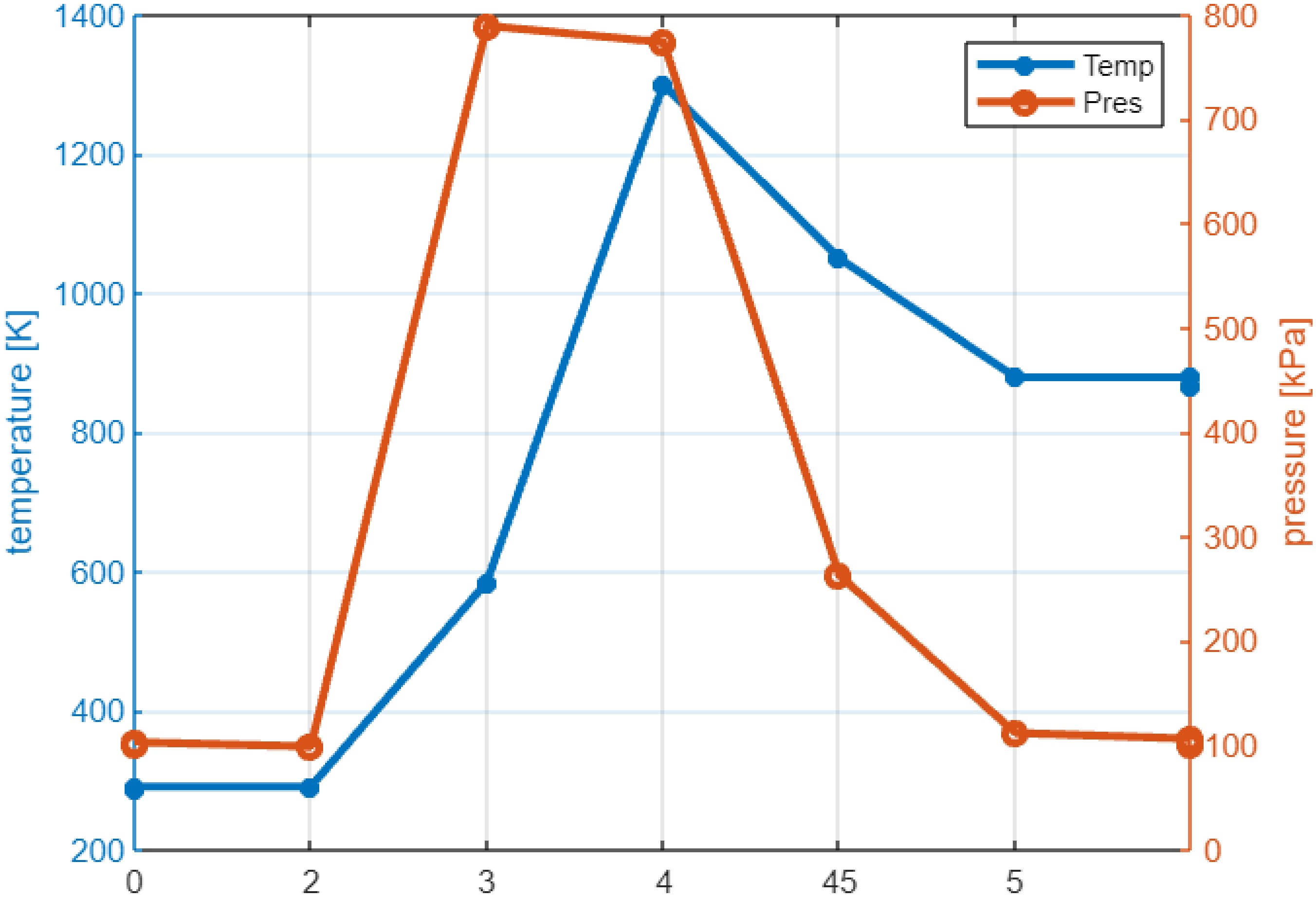


Tabela = 9×3 table

	Section	Temp [K]	Press [kPa]
1	'0'	288	100
2	't0'	290	102.8281
3	't2'	290	98.7150
4	't3'	585	789.7199
5	't4'	1300	773.9255
6	't5'	1050	263.0774
7	't7'	879	111.7063
8	't9'	879	106.1210
9	'9'	866	100

TURBOPROP MASS FLOW AND ENGINE PERFORMANCE CALCULATION

Power turbine work [J/kg]

$$W_{\text{PT}} = c_{\text{pt}}(1 + f_B)(T_{\text{t45}} - T_{\text{t5}})$$

```
WPT = 2.0393e+05
```

Shaft turbine work

$$W_{\text{SP}} = \eta_G \; W_{\text{TP}}$$

```
WSP = 1.9373e+05
```

Air mass flow calculation for defined power [kg/s]

$$m_0 = \frac{P_{\text{SP}\,D}}{W_{\text{SP}}}$$

```
m0 = 51.6169
```

Fuel consumption [kg/s]

$$m_f = m_0 f_B$$

```
mf = 1.0513
```

Specific fuel consumption   [kg/kW/s]

$$\text{SFC} = \frac{m_{\text{fB}}}{P_{\text{SP}\,D}}$$

```
SFC = 1.0513e-04
```

Specific fuel consumption   [kg/kW/h]

$$\text{SFC} = \text{SFC} * 3600$$

```
SFC = 0.3785
```

Thermal efficiency

$$\eta_{\text{th}} = \frac{W_{\text{SP}} + (1 + f_B) * \frac{{V_9}^2}{2} - \frac{{V_0}^2}{2}}{f_B * \text{FHV}}$$

```
etha_th = 0.2361
```

THRUST AND OTHER PERFORMANCE PARAMETERS CALCULATION

Evaluate propeler and overall engine thrust and other engine parameters like SFC and efficiencies refered to overall thrust for engine calculated above. Assume that propeller efficiency is 0.85 and that outlet and inlet engine flow is axial.

Propeller thrust [N]

$$T_P = \frac{\eta_P \, P_{\text{SP}}}{V_0}$$

```
TP = 1.2494e+05
```

Overall thrust [N]

$$T = T_P + m_0\left((1 + f_B) * V_9 \ - V_0\ \right)$$

```
T = 1.3056e+05
```

Specific thrust [Ns/kg]

$$\text{ST} = \frac{T}{m_0}$$

```
ST = 2.5293e+03
```

Propulsive efficiency

$$\eta_p = \frac{V_0 * \text{ST}}{W_{\text{SP}} + (1 + f_B) * \frac{{V_9}^2}{2} - \frac{{V_0}^2}{2}}$$

```
etha_p = 0.8323
```

Overall efficiency

$$\eta_o = \frac{V_0 * \text{ST}}{f_B * \text{FHV}} = \eta_{\text{th}} * \eta_p$$

```
etha_o = 0.1965
```

Temperature - entropy plot

Entropy growth is calculated from equations:

Inlet entropy grow   [J/kg/K] :

$$\Delta s_{\text{IN}} = -R * \ln(\sigma_{\text{IN}})$$

```
dS_IN = 11.7159
```

Compressor entropy grow   [J/kg/K] :

$$\Delta s_C = c_p * \ln\frac{T_{t3}}{T_{t2}} - R * \ln(\text{CPR})$$

```
dS_C = 106.9779
```

Combustor entropy grow   [J/kg/K] :

$$\Delta s_B = c_{\text{pB}} * \ln\frac{T_{t4}}{T_{t3}} - R_t * \ln(\sigma_B)$$

```
dS_B = 964.5563
```

Compressor turbine entropy grow   [J/kg/K] :

$$\Delta s_T = c_{\text{pt}} * \ln \frac{T_{\text{t45}}}{T_{\text{t4}}} - R_t * \ln\left(\frac{P_{\text{t45}}}{P_{\text{t4}}}\right)$$

```
dS_T = 62.6050
```

Power turbine entropy grow   [J/kg/K] :

$$\Delta s_{\text{PT}} = c_{\text{pt}} * \ln \frac{T_{\text{t5}}}{T_{\text{t45}}} - R_t * \ln\left(\frac{P_{\text{t5}}}{P_{\text{t45}}}\right)$$

```
dS_PT = 40.5810
```

Nozzle entropy grow   [J/kg/K] :

$$\Delta s_N = -\text{Rt} * \ln(\sigma_N)$$

```
dS_N = 14.8751
```